Nanotubes

by B. Virtual

Remember the bucky ball? The carbon-based molecular structure that gained fame in K--12 classrooms everywhere. The problem was, as much as Tom Brokaw and Bill Nye sang its praises, no one could really tell what the bucky ball could be used for. We're still trying to figure it out, in fact.

Enter the bucky ball's illegitimate son, the nanotube.

Nanotubes, once considered the waste material that sat at the bottom of chambers used for making bucky balls, are being looked at with newfound respect by physicists, electrical engineers, and computer and materials scientists. What's more, their applications seem to be growing as fast as the nanotubes themselves, such as:

- Television the depth of a framed print that uses far less power than present-day FED's, where silicon does the electron-emitting.
- Nano-memory: Computer memory that's 1,000 times smaller than what currently is possible.
- Nano-Velcro: which could be 100 times stronger, and 10 times lighter, than steel.

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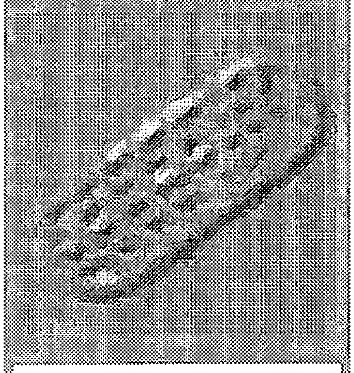

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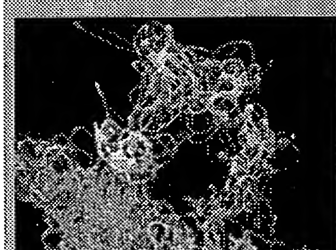

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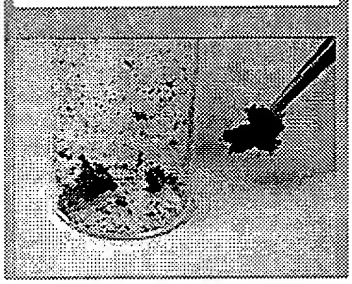

quantities," explains David Tomanek, professor of physics at Michigan State. He and electrical and computer engineers Virginia Ayres and Dean Aslam are embarking on a project to grow and study nanotubes for use in consumer-related applications.

Ayres and Aslam extol the virtues of both diamonds and nanotubes, proposing that, in some cases, a diamond--nanotube hybrid might be the best bet. Such is the case with field emission displays (FED), also referred to as flat-panel displays, a new technology that could revolutionize the way televisions are manufactured.

The reason a television currently occupies so much space in the living room is because three electron guns are firing electrons from the back, line by line, at individual pixels on the screen. Electrons hit the phosphor pixels, and, wham! Homer Simpson is yelling at Bart. Applied to FED technology, molecule-sized nanotubes would emit the electrons instead of the electron guns, with the precision of one nanotube per pixel. The result would be a television the depth of a framed print that, if Ayres and Aslam have it their way, uses far less power than present-day FED's, where silicon does the electron-emitting.

A material's ability to emit electrons is defined by two things: one, the electrical field at the surface (the number of electrons that are buzzing around), and two, the amount of work required to coax the electrons out, called the work function.

Aslam says that for materials with high work functions, like silicon or most metals, sharp edges must be formed to amplify the electrical field at the tip. "If you use a material that has almost zero work function--and that's diamond--then you don't have to make a tip," he says. "But," he adds, "if you can make a tip on top of that..."

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we want to do is reduce that power supply requirement. Otherwise, we have a thin screen, but an enormous, massive power supply. We've defeated our purpose."

For their project, Ayres will be studying the fine line that exists between diamonds and nanotubes by examining the conditions necessary for their growth. Aslam will be conducting the field-emission studies and examining some of the most pervasive questions, namely what is the principal electron-emitting mechanism, and why is emission from diamond, though low in work function, non-uniform in pattern? Tomanek will perform the computer modeling. The three are collaborating with DuPont and NASA Goddard Space Center in their research.

In addition to their use in field emission displays, nanotubes show promise for other applications, says Richard Enbody, associate professor of computer science and engineering. He and Tomanek have applied for two patents that make creative use out of several of the extraordinary properties of nanotubes: nano-memory and nano-Velcro.

"Since all computers are based on the binary system, they only have two states: you can call one of the states 'zero' and one of them 'one,'" explains Enbody. "Therefore, any computer memory, whether it's on a CD ROM, or floppy disk, or hard drive, or RAM, has two states: on and off--zero and one. That's the whole basis for computer memories."

Enbody and Tomanek reason that by putting a bucky ball inside a nanotube, and by getting the bucky ball to slide from one end, the "zero" state, to the other, the "one" state, computer memory could be derived at the smallest known scale.

"This has the potential of making a memory that's 1,000 times smaller than what we have," Enbody said.

Enbody and Tomanek's other idea,

nano-Velcro, or the micro-fastener system, makes use of the inimitable strength of nanotubes, 100 times stronger (and ten times lighter) than steel, and its temperature-resistance, up to 3,000 degrees Kelvin (nearly 5,000 degrees Fahrenheit). They are proposing a hook and loop system, similar to the Velcro flap on a tennis shoe, that uses nanotubes instead. To Enbody and Tomanek, nano-Velcro could be used to manufacture anything--from space shuttles to micro-robots--and would require the same force necessary to form diamond to pull the two sides apart.

"This is about research, Tomanek said. "This is about the next century. This is where we are going."

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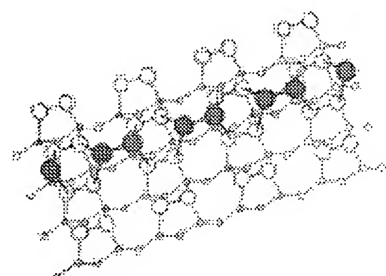
In This Issue . . .

The science of 'small'



Virginia Ayres is *really* small-minded.

So are Syed Hashsham and Jun Nogami. These three MSU researchers, and others like them, are taking the field of engineering and breaking it down to its most base levels—down to where atom collides with atom and DNA strand clings to DNA strand. For them, understanding the minute promises nothing short of the monumental.

What's so great about being small?

When one considers the trends for electronic devices over the years—from laptops to Palm Pilots to cell phones—it should come as no surprise that small is getting to be big these days. Scaling up means sizing down.

"That's one of the big reasons why computers keep getting faster and cheaper," asserts Jun Nogami, associate professor of materials science and mechanics. "We can get more onto a single chip and use less power." Nogami says that, for the past 15 years, computer chips have doubled their capacity every 18 months—a phenomenon known in the field as Moore's Law. He is studying just how far we can go in this direction by growing atom-sized wires—yes, *atom*-sized—to perhaps serve as conductors in tiny circuits.

Sleeker design and less power usage are just two reasons why Ayres and colleague Dean Aslam in the Department of Electrical and Computer Engineering, and Richard Enbody and others in the Department of Computer Science and Engineering are teaming with David Tomanek in the physics department to study the application of nanotubes in flat-panel displays, among other devices. Nanotubes, named for their infinitesimal size occupying the nanometer range (10^{-9} or one billionth of one meter), are hollow, carbon-based tubes that exhibit unique properties in such areas as strength and conductivity. They're also becoming the singular hot topic in engineering circles worldwide.

Environmental engineering, too, is made more powerful by going small. Syed Hashsham, assistant professor of civil and environmental engineering, is applying a new procedure in bioengineering, the microarray technique, to problems in bioremediation and microbial ecology. Through this technique, Hashsham is able to examine the gene expression of a type of bacterium that is capable of breaking down carbon tetrachloride, a suspected human carcinogen. By focusing on the microscopic, Hashsham is able to more clearly see the big picture of how a groundwater contamination problem can be cleaned up in a Michigan community.

wires, as well as ultra-thin films—the kinds of components that would be incorporated into an integrated circuit.

"If we can understand the properties of the wire, then we can start doing things that will bring it closer to what's in a real device," he says.

Nogami is doubtful that a wire the width of one atom will be stable enough to be useful on a microchip. He does believe, however, that by incrementally increasing the size of wires, from one atom to two atoms to ten, he can attempt to answer the ongoing question, "How small can we go?"

"We need to figure out what the one-atom wires do or try to figure out ways of making ten-atom wires that have more of a chance to be usable in a real device," he says. "All kinds of processing steps go on in the construction of a real device," he cautions, "and the creation of these wires is just one step. They still have to survive everything else."

Nanotubes: one-upping the buckyball

Remember the buckyball? The carbon-based molecular structure that gained fame in K-12 classrooms everywhere when Richard Smalley, a professor at Rice University, won the Nobel Prize in Chemistry for its discovery. The problem was, as much as Tom Brokaw and Bill Nye sang its praises, no one could really tell what the buckyball could be used for. We're still trying to figure it out, in fact.

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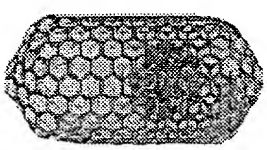
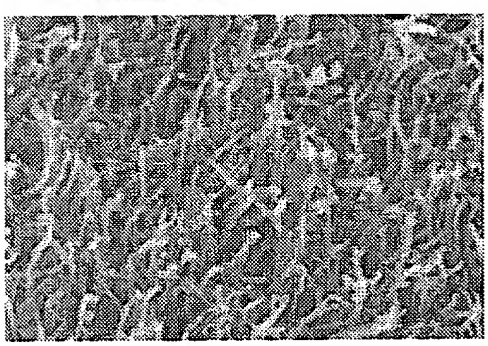
In the world of carbon—to scientists, one of the truly fascinating worlds around—basic forms include graphite, flat sheets of carbon atoms; diamond, perfect tetrahedral arrangements of carbon atoms; and buckyballs, soccer-ball-like structures, the largest and most common form composed of 60 carbon atoms tightly linked together in hexagons and pentagons. Nanotubes are not a new form of carbon; they simply combine the molecular configurations of graphite and buckyballs, taking advantage of the properties of both. The tube is formed when two ends of graphite join together—like chicken wire around a post—and half a buckyball attaches at each end. Although nanotubes could feasibly grow to lengths ad infinitum, the simplest model looks something like a quilted cold capsule. Simple? Hardly.



A model of the nano-memory device: a buckyball inside a closed-off nanotube.



Nanotubes can resemble a microscopic field of grass.

"The synthesis of buckyballs and nanotubes generally produce very small quantities," explains David Tomanek, professor of physics at Michigan State who has co-authored papers with Smalley and Sumio Iijima, the discoverer of nanotubes. He and electrical and computer engineering associate professors Virginia Ayres and Dean Aslam are embarking on a project to grow and study nanotubes for use in consumer-related applications.

"One way to grow them is by shining a laser beam on evaporating graphite; the other is by creating a carbon arc between two graphite electrodes. Both techniques produce very little," he explains. "Only recently, however, someone produced beautiful arrays of nanotubes using a process called plasma deposition. Suddenly, people are saying, isn't plasma deposition used by those people in diamond films?"

True. And that's where Ayres and Aslam fit in. For years, they have been loyally employing this method to grow and study diamond films for use as sensors, microelectromechanical systems (MEMS) devices, and electron-emitters. In plasma deposition, a "plasma" or chemical mixture consisting of carbon-rich gases such as methane, is subjected to intense energy—sometimes microwaves, sometimes hot filaments—that converts the molecules into atoms, which, in turn, form layers of polycrystalline diamond. Already, Ayres has discovered that if she tweaks the growing conditions for diamonds in very controlled ways in these very same reactors, nanotubes will form instead.

(l–r) Dean Aslam, David Tomanek, and Virginia Ayres have teamed up to study the growing conditions and properties of nanotubes.

"What we are changing are its circumstances," she explains. "We change the amount of energy that is available on the growing film surface. We change the amount of carbon atoms that are available to be put down. And in doing so, we change the morphology—we change the physical structure." Ayres is investigating the role that nitrogen, an element that makes up 78 percent of the atmosphere, plays in catalyzing the reaction, and therefore in altering the above conditions.

Ayres and Aslam aren't ready to abandon their diamond studies, however. Rather, they extol the virtues of both materials, proposing that, in some cases, a diamond-nanotube hybrid might be the best bet. Such is the case with field emission displays (FED), also referred to as flat-panel displays, a new technology that could revolutionize the way televisions are manufactured.

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Bart and Mike Wallace is interrogating yet another wrongdoer. Applied to FED technology, molecule-sized nanotubes would emit the electrons instead of the electron guns, with the precision of one nanotube per pixel. The result would be a television the depth of a framed print that, if Ayres and Aslam have it their way, uses far less power than present-day FED's, where silicon does the electron-emitting.

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Exciting as the prospects are, we're still at the beginning phases—where researchers are simply trying to grow the nanotubes, to shape them, and to handle them.

Nevertheless, MSU's team is the picture of optimism.

"This is about research. This is about the next century. This is where we are going," says Tomanek.

Major gift for MSU engineering advances computer-aided design

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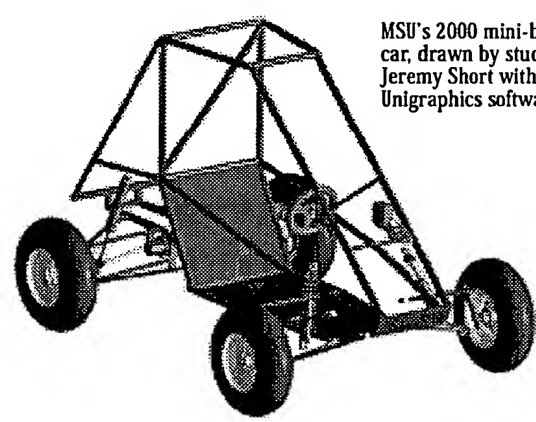

MSU's 2000 mini-baja car, drawn by student Jeremy Short with Unigraphics software.

It can happen in the shower, at a stoplight, on the treadmill, in the check-out aisle. A great idea strikes—fast—hitting us cold out of who-knows-where. So it must be frustrating to experience one of these lucid moments of inspiration, only to wait another three or four years until it's finally put into play.

Such has been the dilemma of America's auto makers, where it can take roughly 50 months before a great idea gets wheels. Thanks to a new alliance between four forward-thinking companies and Michigan State University's College of Engineering, however, we're now poised to up that pace.

PACE, the Partnership for the Advancement of CAD/CAM/CAE Education, is the unified effort of General Motors, Unigraphics Solutions (UGS), Sun Microsystems, and Electronic Data Systems (EDS) to more amply equip up-and-coming engineers. The four organizations are committing $190 million (fair market value) in computer hardware, software, training, and support to 40 key universities in the areas of computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE). Michigan State University has been designated to receive the first and largest of the gifts-in-kind: 110 work stations, training, and support valued at $30 million. Universities in the United States and Mexico will follow in the next three years.

"It used to be that designers would dream up the overall design of a product and then those involved in engineering analysis and in manufacturing would determine if the products were feasible or could be made," explains Nicholas Altiero, chairperson of the Department of Materials Science and Mechanics and the partnership's principal liaison from MSU. "PACE is hoping to stimulate universities to prepare 'designing engineers'—engineers who can function in teams that are capable of doing it all concurrently."